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Studies of Flux and Spectral Variability of Blazars

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Introduction:

Blazars are the extreme subclass of Active Galactic Nuclei (AGN) which consists of BL Lacertae (BL Lacs) and Flat Spectrum Radio Quasars (FSRQs). They are identified as the jet pointing towards the observer within the 10° of line of sight (Urry & Padovani et al. 1995). They are observed across the whole electromagnetic spectrum from radio waves to very high energy gamma-rays at different timescales (Ulrich et al. 1997, Wagner et al. 1995, Gupta et al. 2008, Gaur et al. 2012, Pandey et al. 2017, Bhoomika et al. 2020, Raiteri et al. 2021 and references therein). Flux variability on different timescales with high & variable radio/optical polarisation are the main characteristics of blazars (Gaur et al. 2014, Blinov et al. 2015, Lyutikov et al. 2017).

Spectral Energy Distribution (SED) of blazars consists of a broad double-peaked structure (Giommi, Ansari & Micol 1995; Fossati et al. 1998). First hump at lower energies (sub-millimeter wavelengths to X-ray energies) is attributed to synchrotron emission due to relativistic electrons in the jet. Second hump at higher energies (hard X-rays up to TeV gamma-rays) is believed to be originated from the inverse Compton scattering of the same electron population with the synchrotron photons i.e Synchrotron Self-Compton (SSC)(Kirk, Rieger & Mastichiadis 1998, Marscher & Gear 1985) or through an external Compton (EC) with the seed photons originate external to the emission region (Dermer et al. 1992, Ghisellini et al. 1998). Hadronic Models are also viable to explain the high energy emission which is produced by a cascade induced by the interaction of high-energy protons with the ambient photons (Mannheim 1993, Böttcher et al. 2013, Cerruti et al. 2015). Based on the location of synchrotron SED peak, Blazars are classified in three categories as high spectral peak blazars (HSP, $v_p > 10^{15}$ Hz), intermediate spectral peak blazars (ISP, 10^{14} Hz < $v_p <= 10^{15}$ Hz) and low spectral peak blazars (LSP, $v_p <= 10^{14}$ Hz). (Abdo et al. 2010, Fan et al. 2016).

Blazars show rapid flux variability on different timescales of hours to few days and few months to years (Ulrich et al. 1997, Albert et al. 2007, Pandey et al. 2017, Raiteri et al. 2021). When blazars show a change in flux within a day then it is referred to as an intra-day variability (IDV); when it is for few days to few months then it is termed as short term variability (STV) and when the variability spans for a year or for longer period then it is referred as long term variability (LTV) (Gupta et al. 2004).

Literature Review:

Flux variability at different timescales leads to different sizes of emitting regions and flux variability along with spectral variability across the whole electromagnetic spectrum gives us the information of these different emitting regions. (Pandey et al. 2017, Kapanadze et al. 2016, Kapanadze et al. 2018 and references therein). Basic model explaining the variability in blazars consist of Shock-in-jet model triggered by the shock interaction with the jet inhomogeneities or turbulence behind a shock or magnetic reconnection events (Marscher & Gear 1985, Marscher 2014).

The synchrotron component of SED of blazars is well described by the log-parabolic energy distribution of the relativistic electron population. (Massaro et al. 2004, Tramacere et al. 2007, Chen 2014, Wani et al 2020, Shah et al. 2021). Flux distributions for blazars are found to be log-normal distribution rather than a normal distribution (Giebels & Degrange 2009, Tluczykont et al. 2010, Shah et al 2018, Kushwaha et al. 2016, Ackermann et al. 2015, Sinha et al. 2016). Blazars have shown a harder-when-brighter trend i.e. the spectrum gets harder with increasing flux, and subsequently, the peak of the synchrotron emission shifts toward higher energies. The hardening of spectra and shift in synchrotron peak E_p is linked to the particle energization. (Kapanadze et al. 2016 & 2018, Chandra et al. 2021).

X-ray observations are important in order to understand the driving physical mechanism of blazars. X-ray variability is observed to be linearly correlated with the flux level which means that source is more variable when it is brighter and it implies that underlying physical process is multiplicative and that the long term variations should modulate the short-term variations (Gaskell 2004, Uttley, McHardy & Vaughan 2005, Bhattacharya et al. 2020). X-ray spectral variations of synchrotron peak in blazars are used to study the possible relation between the spectral parameters of the log-parabolic model and the black hole mass (M_{BH}) (Wang et al. 2019).

Optical studies are important to understand the colour behaviour of blazars. BL Lacs follow a BWB (bluer-when-brighter) trend than do FSRQs and it can be attributed to the more dominant jet emission in the case of BL Lacs and the contribution of thermal emission from the accretion disc for FSRQs (Negi et al. 2021, Agarwal et al. 2019). Partial trends of BWB or RWB (redder-when-brighter) nature (or occasionally both) i.e. the complex colour behaviours observed in the colour-magnitude diagrams of the blazars may result from transitions between the jet-dominated state and the disc-dominated state and vice versa. (Zhang et al. 2015, Negi et al. 2021)

Roma-BZCAT catalogue consists of 2728 blazars which was based on multi-frequency surveys and on an extensive review of the literature (Massaro et al. 2009). The new 3561 sources are recently updated in the catalogue (Massaro et al. 2015). In the catalogue Blazars were classified as BL Lacs (BZB), FSRQs (BZQ), and blazars of uncertain/transitional type (BZU). Majority of the blazars from the

catalogue are never studied for optical variability properties on diverse timescales. Recently, Kalita et al. 2021 studied the optical variability properties of Roma-BZ catalogue blazars. They showed significant negative colour–magnitude correlations i.e., a redder-when-brighter spectral evolution. They reported that the non-variability in the BL Lacs in their sample could be resulted by distinct contribution from the disk as well as from other components in the studied energy range.

Objective:

Our main aim is to investigate flux and spectral variability of blazars in X-ray and optical bands using various space and ground based telescopes. This will help us to understand the variability mechanism of blazars.

Main objectives are as follows:

1) We study X-ray flux and spectral variability of TeV blazars using XMM-Newton and Swift satellites in order to investigate their variability mechanism and correlations between their spectral parameters (during flaring / low states).

2) ROMA-BZCAT catalogue of blazars consists of thousands of newly discovered blazars (BL Lacs + FSRQs). We have derived a sample of 10 blazars which are never studied for flux and spectral variability and we are observing them using 1.04 m ST and 1.3 m DFOT telescopes at ARIES.

Methodology:

For the proposed study of blazars we will use the data obtained by various ground based and space based telescopes available in X-ray and optical energy bands.

<u>X-ray Data:</u>

For an energy range of 0.3-10 keV we will collect the data obtained by XMM-Newton and SWIFT space based telescopes.

X-ray data analysis will be done with the use of the HEAsoft tools and standard pipeline. Also we will use the Science Analysis System (SAS) for the X-ray analysis of XMM-Newton data (Gabriel 2017). XRT Data Analysis Software (v.3.6.0) which is a part of the HEASoft package (v.6.28) will be used for the data reduction of SWIFT data.

<u>Optical Data:</u>

Optical data will be observed and obtained from ARIES 1 m class telescopes (1.3 m DFOT and 1.04 m ST) in the BVRI band.

We will use IRAF (Image Reduction and Analysis Facility) and DAOPHOT-II (Dominian Astrophysical Observatory Photometry) to do basic image reduction (including bias correction, flat fielding, cosmic ray correction & alignment) and the optical aperture photometry respectively.

Analysis Techniques:

We will use three statistical techniques mainly to quantify the X-ray variability studies. They are as follows: fractional variability amplitude (F_{var}) (Vaughan et al.

2003), Discrete correlation function (DCF) and Power spectral density (PSD). F_{var} will be used to quantify the intrinsic variations shown by the blazars. DCF will be used to correlate different energy bands. PSD will be used to measure the variability power as a function of temporal frequency and is used to characterise the noise processes in general. The slopes of the PSD suggests the emission mechanism of blazar i.e either turbulence behind a shock or instabilities in the accretion disc as the origin of the observed variability (Gaur et al. 2018, Zhang et al. 2019)

Statistical tests like F-test (Howell et al. 1988) and Analysis of variance test (ANOVA test) (de Diego et al. 2010) will be used to study the variability characteristics of the selected sample of ROMA-BZCAT catalogue blazars .

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